

## **Refrigerant Compression System with Selective Subcooling**

### **Background of the Invention**

[0001] This invention relates generally to vapor compression refrigeration systems and, more particularly, to a method and apparatus for subcooling refrigerant in a transport refrigeration system.

[0002] In many refrigeration systems, such as those for preserving food in supermarkets, refrigerators and the like, the load is substantially fixed and the demands of the system are substantially constant throughout the life of the system.

[0003] Transport refrigeration systems are different. As the types of food products that are being transported in refrigerated trucks, trailers and containers are always changing, the temperatures at which these products are desirably maintained also change. For example, one day the cargo of a truck may be bananas, with the desired temperature to be maintained at 57° degrees. On the next day, the same trailer may be hauling frozen goods, and the desired temperature to be maintained in the trailer would be 0°F or below. They also must be able to operate in all ambient conditions as they are portable and need to be able to operate all over the world. Because of this wide range of demands, the design of a refrigeration system for a transport truck/trailer must therefore be very flexible. Thus, they must be designed to meet the maximum capacity requirements, but they are preferably designed to operate efficiently and precisely at much lower capacity requirements during most of their operating life.

[0004] Various marketing conditions have tended to exacerbate the problems of meeting the capacity requirements of transport refrigeration systems as discussed hereinabove. For example, because of environmental concerns, it has become necessary to abandon the use of more efficient, but environmentally undesirable, refrigerants, and to replace them with refrigerants that are less efficient. Another development that has occurred because of the need for greater cargo capacity and overall efficiencies, is a tendency to lengthen the refrigerated trailers, and also construct them with thinner side walls.

[0005] Current single stage compression systems have limited capacity and cannot meet the market needs as discussed hereinabove. The use of subcooling and refrigeration systems has long been used but the systems have generally been relatively complex, expensive, and difficult to maintain. Examples of such systems include those with suction liquid heat exchangers, subcoolers in condenser coils, and mechanical subcoolers using separate compressors or economizer subcoolers in multi-compressor staged systems.

[0006] It is therefore an object of the present invention to provide an improved transport refrigeration system.

[0007] Another object of the present invention is the provision in a transport refrigeration system to selectively operate at higher capacity levels in an easy to use and efficient manner.

[0008] Yet another object of the present invention is the provision in a transport refrigeration system for operating at a lower capacity level in a reliable and efficient manner.

[0009] Still another object of the present invention is the provision for transport refrigeration systems which can be readily and easily boosted in its output capacity.

[0010] Yet another object of the present invention is the provision for a transport refrigeration system which is economical to manufacture and effective and efficient in use.

[0011] These objects and other features and advantages become more readily apparent upon reference to the following description when taken in conjunction with the appended drawings.

### **Summary of the Invention**

[0012] Briefly, and in accordance with an aspect of the invention, a single compressor of a transport refrigeration system is provided with two sections, with one section being connected to the main system evaporator, and the other section being connected to a subcooling evaporator. An isolation valve and an expansion

device are in the subcooler unit so as to allow for control and isolation of the subcooler when not required.

[0013] In accordance with another aspect of the invention, a multiple cylinder reciprocal compressor is provided with one or more cylinders being dedicated to use in the subcooler circuit, while the other cylinders are dedicated to the main evaporator circuit.

[0014] By yet another aspect of the invention, one or more unloading circuits are provided in the main section of the compression system such that the compressor can be unloaded during periods of low capacity demand.

[0015] In the drawings as hereinafter described, a preferred embodiment is depicted; however, various other modifications and alternate constructions can be made thereto without departing from the true spirit and scope of the invention.

#### **Brief Description of the Drawing**

[0016] Fig. 1 is a schematic illustration of a refrigeration system in accordance with a preferred embodiment of the invention.

[0017] Fig. 2 is a graphic illustration of the pH diagram of the cycle of that system.

[0018] Fig. 3 is a schematic illustration of an alternate embodiment of the invention.

[0019] Fig. 4 is a schematic illustration of yet another embodiment of the invention.

#### **Description of the Preferred Embodiment**

[0020] Referring now to Fig. 1, a vapor compression system for use in a transport refrigeration system, such as a refrigerated truck, trailer or container is shown to include a compressor 11 (shown generally in dashed lines), a condenser 12, an expansion device 13 and an evaporator 14, which are connected within a closed circuit to be operated in a conventional manner.

[0021] The compressor discharge port 16 is connected to discharge to the condenser 12 by way of the valve 17, which can be selectively opened or closed for the purpose of isolating the compressor for service, and by the discharge check valve 15. Downstream of the condenser 12, a receiver 18 and an associated valve 19 may be included.

[0022] Expansion valve 13 is placed just upstream of the evaporator 14 and is responsive to a sensor 21 that senses the temperature of the refrigerant at the downstream end of the evaporator 14 so as to maintain a slightly superheated refrigerant condition. The superheated refrigerant then flows along the line 22 through a valve 23 to a compressor suction inlet 24. The compressor suction inlet 24 is one of two compressor suction inlets as will be described hereinafter.

[0023] In order to obtain greater capacity from the compressor 11, a subcooler 26 is provided upstream of the evaporator 14. Upstream of the subcooler 26, a line 27 divides into lines 28 and 29, with line 28 passing through the subcooler 26 by way of the heat exchanger element 31 and then by way of line 32 to the expansion device 13. A line 29 is fluidly interconnected to a valve 33, a second expansion valve 34, a heat exchanger element 36 and out to line 37. A sensor 38 is interconnected to the expansion valve 34 so as to allow the expansion valve 34 to be responsive to the temperature of the refrigerant leaving the subcooler 26. Line 37 is connected by way of valve 38 to another compressor suction inlet 39 as shown.

[0024] In operation, during periods in which the system demand calls for relatively low capacities, the valve 33 is in the closed position and the subcooler 26 is effectively removed from the circuit. The refrigerant flows through lines 27, 28, and through the heat exchanger element 31, to the line 32 and the expansion valve 13. Downstream of the evaporator 14, the refrigerant passes into the compressor suction inlet 34, is compressed in a manner as will be described hereinafter, and is discharged at the compressor discharge port 16.

[0025] During periods of operation wherein greater capacities are required, the valve 33 is opened to allow the flow of refrigerant through line 29, the valve 33, the expansion valve 34, and into the heat exchanger element 36. Because of the

expansion of the refrigerant in the expansion valve 34, the heat exchange element 34 is cooled, but with the heat exchanger element 36 being in heat exchange relationship with the heat exchanger element 31, the transfer of heat causes a cooling of the refrigerant flowing through the heat exchanger element 31, such that the temperature of the refrigerant entering the expansion valve 13 is subcooled. As the subcooled refrigerant passes into the evaporator, it results in a substantially greater performance of the evaporator 14.

[0026] Considering in greater detail the compressor 11, it will be seen that the compressor 11 is a multiple cylinder reciprocating compressor. Five of the six cylinders are interconnected to provide compression between the suction inlet 24 and the discharge port 16. These are shown at 41-46. Each of the cylinders has a suction valve 47, a piston 48 and a discharge valve 49 as shown. A pair of unloaders 51 and 52 are provided to selectively connect the high pressure side back to suction as shown in order to reduce the capacity when it is not needed. Check valves 53 and 54 are also preferably provided on the high pressure side as shown.

[0027] Referring now to the sixth cylinder 56, this cylinder provides compression between the compressor suction inlet 39 and the compressor discharge port 16. It is identical to the other cylinders in that it has a suction valve 47, a piston 48 and a discharge valve 49, but it may well have a different displacement than the other cylinders. During periods in which the subcooler is activated within the system by the opening of the isolation valve 33, the cylinder 56 will compress the refrigerant being discharged from the subcooler 26, with the compressed refrigerant being mixed with that compressed by the other five cylinders of the compressor 11. During periods in which the additional capacity is not required, the isolation valve 33 will be closed and the cylinder 56 will continue to function but will not perform any work. The isolation valve 33 could be integrated with the expansion device 34 by use of an electronic expansion valve as will be more fully discussed hereinafter.

[0028] When full capacity is required, all six cylinders will be compressing refrigerant and the evaporator unit will be boosted by use of the subcooled refrigerant. When full capacity is not required, it may be reduced by turning off the

subcooler or partially closing down the subcooler 26, or by using one or both of the unloaders 51 and 52, or a combination of these approaches.

[0029] Referring now to Fig. 2, the pH diagram of the system is shown when using R-404A as the refrigerant. The points 1-7 represent the positions on the chart which corresponds with the positions 1-7 within the system cycle as shown in Fig. 1.

[0030] At point 1, upstream of the expansion valve 13, the refrigerant is at a relatively high pressure and low temperature. At point 2, just downstream of the expansion valve 13, the pressure is substantially reduced, and at point 3, just upstream of the compressor suction inlet 24, the pressure is relatively low and the temperature is substantially increased. After passing through the compressor, the temperature and pressure are increased to point 4 and after passing through the condenser at position 7, the pressure remains almost constant but the temperature is substantially reduced. Finally, passing of the refrigerant along line 28 and through the subcooler 26 cools the refrigerant to the point 1 temperature.

[0031] Considering now what occurs in the other line 29 of the subcooler 26, the passing of the refrigerant through the expansion valve 34 reduces the pressure to that at point 5, and after passing through the subcooler 26 the temperature of that refrigerant is increased to that shown at point 6.

[0032] Referring now to Fig. 3, an alternative embodiment is shown wherein the isolation valve 33 and the expansion valve 34 are replaced with an electronic expansion device 57 upstream of the subcooler 26 as shown. The electronic expansion device 57 is controlled by a controller 58 which automatically adjusts the electronic expansion device 57 toward the closed or open conditions in response to various sensed and programmed parameters.

[0033] On the downstream side of the subcooler 26, the sensors 59 and 61 sense pressure and temperature, respectively, of the refrigerant in lines 37 and input those values to the controller 58. Other inputs, such as saturation point, ambient temperature, suction pressure and discharge pressure, are input into the controller 58 by way of line 62.

[0034] In response to the various input signals and the programmed software embedded therein, the controller sends signals along lines 63, 64 and 66 to control the electronic expansion device 57, the unloading function, and the compressor speed, respectively, in order to optimize the system operation in a controlled and efficient manner.

[0035] Another embodiment of the present invention is shown in Fig. 4 wherein, a three way valve 67 is provided in line 37 and ties into line 22 by way of line 68. The three way valve 67, which can be controlled by solenoid 69, would enable the six cylinder 56 to be able to use suction gas from line 37 as described hereinabove, but it also can be used to bring in suction gas from line 22, along line 68, to thereby permit the compressor to act as a full six cylinder machine on gas from the evaporator 14, or as a subcooling cylinder as described hereinabove. One advantage of this arrangement is that the subcooler 26, and all joints up to the compressor suction valve 38, would not be under negative pressure when shut off. A possible disadvantage is the need for a three way valve, which is generally not considered to be particularly reliable.

[0036] While the present invention has been particularly shown and described with reference to a preferred embodiment as illustrated in the drawings, it will be understood by one skilled in the art that various changes in detail may be effected therein without departing from the true spirit and scope of the invention as defined by the claims. For example, although the compressor has been described in terms of a six cylinder reciprocating compressor with five cylinders dedicated to one section and one cylinder to the other section, it may just as well be separated at different ratios, such as four and two, or it may have a different number of cylinders, such as one and one in a two cylinder machine, or three and one in a four cylinder machine, for example.